Precision Signal Power Measurement and Noise-Adding Radiometer Equipment

L. C. Constenla
Communications Systems Research Section

A new Precision Signal Power Measurement equipment incorporating a Noise-Adding Radiometer technique has been developed for precise measurement of spacecraft signal power returns. This equipment continuously measures the receiver system noise temperature, signal-to-noise ratio, and received signal power in real time during actual spacecraft tracking. The operation of this system requires that a precisely known amount of noise be switched on and off at the receiver input. This increase in noise is detected and used as a reference in the determination of the receiver system noise temperature. In turn, the system temperature is used to calculate the received signal power.

The Precision Signal Power Measurement equipment is presently installed in the Pedestal Room of the DSN 64-m-diameter antenna at the Mars Deep Space Station (DSS 14). The system was successfully tested during the Helios track on 2 October 1975, recording an averaged received carrier power of −140.6 dBm, which was in close agreement with the calibrated automatic gain control (AGC) method used by the station.

I. Introduction

A new single-rack stand-alone Precision Signal Power Measurement (PSPM) and Noise-Adding Radiometer (NAR) equipment was built and installed in the Pedestal Room at the Mars Deep Space Station. This system digitally measures the receiver system noise temperature, signal-to-noise ratio (SNR), and received signal power in real time during spacecraft tracking. The equipment is permanently connected through isolation amplifiers to the BLOCK III receivers 1 and 2, and BLOCK IV receivers 3 and 4, 50- and 55-MHz intermediate frequencies (IF), respectively. The NAR operation makes use of the existent noise diode boxes installed in the antenna S- and X-band feedcones.

The PSPM system is designed to be operated either locally as a stand-alone unit or remotely under control of a supervisory computer via a Network Operations Control

Center (NOCC) Standard Interface. Once in operation, all processing and control are done locally by a dedicated minicomputer that is part of the system.

The measured parameters are automatically displayed on a front panel read-out as well as printed on a teletypewriter (TTY) and/or sent to the supervisory computer for further processing and storage. The system is capable of measuring signal power levels between -125 and -190 dBm with an rms error less than 0.2 dBm for signals stronger than -175 dBm.

II. PSPM and NAR Equipment

A simplified block diagram of the equipment used to implement the PSPM and NAR techniques is shown in Fig. 1. Any one of the four available receiver IF signal channels can be selected as input to the equipment. Table 1 shows the characteristics of these IF signal channels. The signal selected is then split into the NAR and PSPM sections of the equipment.

The NAR portion of the equipment uses a new Broadband Square Law Detector (Ref. 1) as a total-power radiometer detector. The analog voltage output of this device is sampled at a 500-Hz rate by an A-D converter and entered in the computer as data. The NAR scheme also requires that a constant amount of noise be added to the receiver input. This is accomplished by switching a reference noise diode source on and off under computer control as shown.

In the PSPM section of the equipment, the signal is first bandpassed by a 50/55-MHz tunable filter and then mixed down to 10-MHz IF and filtered again. A second mixer translates the IF signal to baseband, which is then fed into the low-pass filters.

A set of three 6-pole active low-pass Chebyshev filters with a 0.1-dB ripple in the passband and cutoff frequencies of 22, 220, and 2200 Hz is provided as anti-aliasing filters for the PSPM power spectrum operation. Its outputs are sampled at rates of 50, 500, and 5000 Hz, respectively, by the A-D converter and entered via direct memory access (DMA) in the computer as a table of data points. The first and second local oscillators (LO) and the sampling frequencies of both A-D converters are coherent with respect to the receiver reference frequency. A small CRT display unit connected to the computer is used as a monitor for the power spectrum operation. Further details of the radio frequency portion of the PSPM are given in Ref. 2.

III. Principle of Operation

The Precision Signal Power Measurement technique is based on the determination of the SNR from a digitally computed narrow-band spectrum analysis of the received signal (Refs. 3, 4, 5, and 6). Since the computed SNR relates the strength of the signal to that of the noise at the input of the receiver, knowledge of the noise power entering the receiver is essential to calculate the signal power. Thus, concurrently with the spectrum analysis process, a Noise-Adding Radiometer process is used to measure the noise temperature of the receiver front end (Ref. 1). The signal power is then calculated from the combined results of these two asynchronous processes.

The Fast Fourier Transform (FFT) method is used to compute the power spectrum of the received signal from its digitally stored samples. Since the sampling process of the signal is coherent with the receiver reference frequency, the location of the signal within the spectrum is precisely known. Furthermore, the tracking action of the receiver causes the signal to appear stationary in frequency.

After accumulating the power spectra of the sampled data for a predetermined amount of time, the computer proceeds to normalize the resulting power spectrum. The principal requirement for the SNR calculation is that the noise be equally distributed throughout the resulting power spectrum, except for the low and high end roll-off regions. The SNR is determined by summing the individual spectral power points in two equivalent regions of the spectrum with one of the regions containing the additional signal power contribution. The detail analysis of the PSPM technique is presented in Ref. 4.

The system temperature is calculated from voltage samples taken from the Broadband Square Law Detector output that is part of the NAR equipment. The detector output voltage V is proportional to the system noise temperature T_{op} as given by

$$V = GKT_{op}$$

where G is the system gain, and K is a scaling factor. The operation begins by turning the noise reference source on and accumulating sample readings for a predetermined period of time. With the noise reference source off, an equal number of readings are taken, and a ratio of output powers (Y factors) is calculated:

$$Y = GK(T_{op} + T_N)/GK(T_{op})$$

where T_N is the equivalent noise temperature of the noise reference diode. The Y factor operation is repeated a given number of times and an average value $\overline{Y}$ is computed. Thus, solving for T_{op},

$$T_{op} = T_N/(\overline{Y} - 1)$$

where T_N is a known constant value, typically around 0.5 K. The noise reference source is measured off-line before tracking, and its value is entered in the computer as an equivalent noise temperature.

IV. Hardware Configuration

A detailed block diagram of the PSPM and NAR equipment hardware configuration is shown in Fig. 2. This diagram shows the interrelation between the PSPM and NAR hardware and the dedicated minicomputer as well as the optional remote control function provided by the supervisory computer.

The final PSPM and NAR implementation was influenced by the on-going effort on the part of JPL to automate the DSN stations. To this effect the equipment was designed to use the recently adopted NOCC Standard Interface to communicate with the station supervisory computer. A second NOCC Standard Interface link between the PSPM and NAR hardware and the dedicated minicomputer is provided for greater system integration flexibility.

The PSPM and NAR hardware uses a PSPM-NAR digital controller to communicate with the dedicated minicomputer via a Standard Interface Adapter (SIA) port. The function of the digital controller is to decode the commands and data sent by the control computer and direct the information to the RF and A-D converters, PSPM control and display front panel, and CRT display unit. Another function of this controller is to send device status, PSPM and NAR data to the control computer.

A Lockheed Electronics Company MAC-16 minicomputer (Ref. 7), modified to include a two-port SIA digital controller, is used as the control computer. This built-in controller connects the two SIA ports to the minicomputer DMA channel, programmed data channel (PDC), and interrupt system. In addition, several of the minicomputer front panel control switches are connected to the SIA port that communicates with the supervisory computer. This provides for complete remote operation of the MAC-16 computer by the supervisory station control computer.

DSN station time is brought into the control computer by means of a NASA 36-bit 1-s time code translator built as part of the digital controller. An ASR 33 teletypewriter is used by the operator to communicate with the PSPM and NAR real-time program.

Any computer having an SIA port, sufficient memory, and one magnetic tape transport can be used as a supervisory computer. Presently, the Pedestal Room XDS 930 computer connected to a 900-series SIA (Ref. 8) is being used as the supervisory computer.

Figure 3 shows the picture of the PSPM and NAR equipment rack. From the picture, some of the main components can be readily identified. At the top of the rack there is a chassis containing all the power supplies used to power the digital controller cage and RF cage. Below is the MAC-16 minicomputer power supply. The Broadband Square Law Detector is used by the NAR equipment for the determination of the system temperature. The RF cage contains the RF and A-D converter modules for the PSPM operation and the A-D converter module for the NAR operation.

The PSPM-NAR digital controller cage contains all necessary controls for the RF cage equipment, digital controller front panel display and control switches, and CRT display unit. Also, the digital controller cage contains the SIA port to communicate with the dedicated MAC-16 minicomputer. The CRT display unit is used as a monitor for the real-time logarithmic display of the calculated received signal power spectra.

The MAC-16 minicomputer is a 16-bit parallel processor with 8000 words of core memory, and 16 levels of interrupt. This minicomputer is used for PSPM-NAR hardware control and PSPM and NAR calculations, as was explained above. A Hewlett-Packard 5100A frequency synthesizer is used as the PSPM equipment first local oscillator. At the bottom of the rack there is the receiver selection patch panel and the rack ac power panel.

V. System Software

The Precision Signal Power Measurement and Noise-Adding Radiometer system software is a real-time program written in MAC-16 LEAP 8 (Ref. 9) assembly language. The entire program, consisting of a main control program, the PSPM and NAR subprograms, and all the working tables, is contained in 8000 words of core memory. Double and triple precision fixed-point math routines were either created or modified to maximize the program speed.

During the system design phase, careful attention was given to the hardware-software interaction to achieve an optimum balance. To this effect, many of the control functions were implemented in hardware, including all the data multiplexing and the entire SIA control function.

VI. Test Results

The PSPM and NAR equipment was tested for the first time during the Helios track on 2 October 1975. For this experiment a measured 0.46-kelvin equivalent noise temperature reference diode was used to calculate the system temperature. The noise diode reference was switched on and off by the equipment at two-second intervals. Every four seconds, a new Y factor ratio was obtained, and these ratios averaged for a period of five minutes. The NAR operation then calculated the average system temperature for that five-minute interval.

Measurements of the received signal power were completed every 3.5 minutes from the combined results of the SNR and system temperature. Figure 4 shows a two-hour plot of the measured receiver system temperature. The decrease in average system temperature results from an increasing antenna elevation angle. The standard deviation, σ_T, computed from a cubic approximation obtained by a least square regression, is 0.168 K, which is equivalent to 0.029 dBm.

The received signal power estimates calculated by the PSPM using a 250-Hz sampling bandwidth and filter is shown in Fig. 5. The standard deviation, σ_p, is 0.064 dBm. The averaged received power remains constant at −140.6 dBm, which was expected from the Helios spacecraft.

VII. Conclusion

An automatic real-time PSPM and NAR equipment is presently installed in the Pedestal Room at DSS 14. The equipment is capable of measuring the receiver-system temperature to a resolution of a few millikelvins and the received signal power from −125 dBm to below receiver detection threshold with a standard deviation of < 0.2 dBm. Initial tests have demonstrated that the system is very accurate, requiring no calibration except for the precise off-line measurement of the noise source diode used as a reference. The equipment built for research, development, and demonstration can be easily interfaced to the station equipment via an SIA.

References

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Table 1. Receiver IF channel characteristics

Block III receivers (S-band)	
	IF $=$ 50 MHz
	BW $\approx$ 10 MHz @ -3 dB
	$P_N \approx -30$ dBm for $T_{op} = 20$ K
Block IV receivers (S, X-band)	
	IF $=$ 55 MHz
	BW $\approx$ 36 MHz @ -3 dB
	$P_N \approx -35$ dBm for $T_{op} = 20$ K

NOTE: P_N = available noise power at power splitter input
T_{op} = system noise temperature

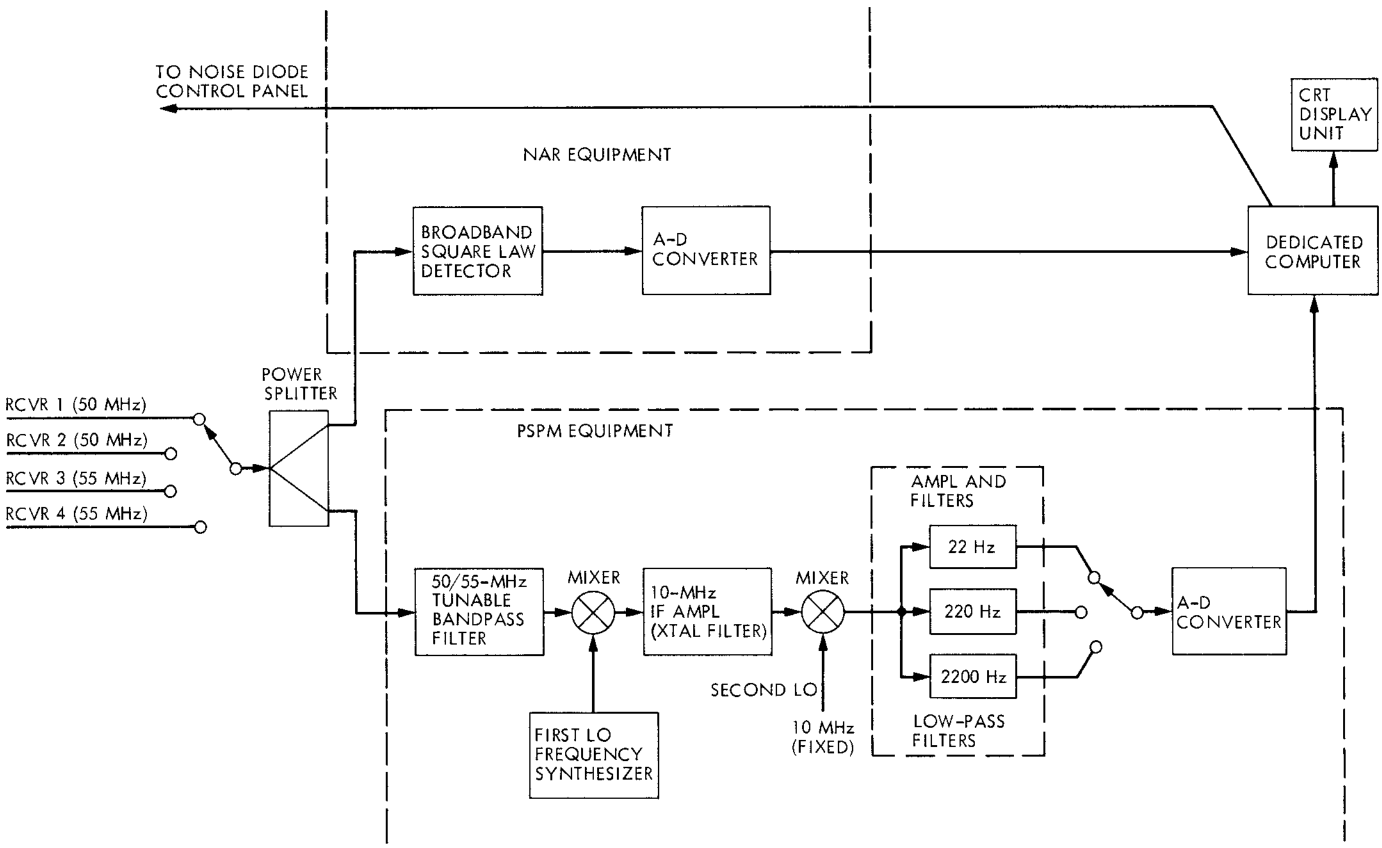

Fig. 1. **PSPM and NAR system block diagram**

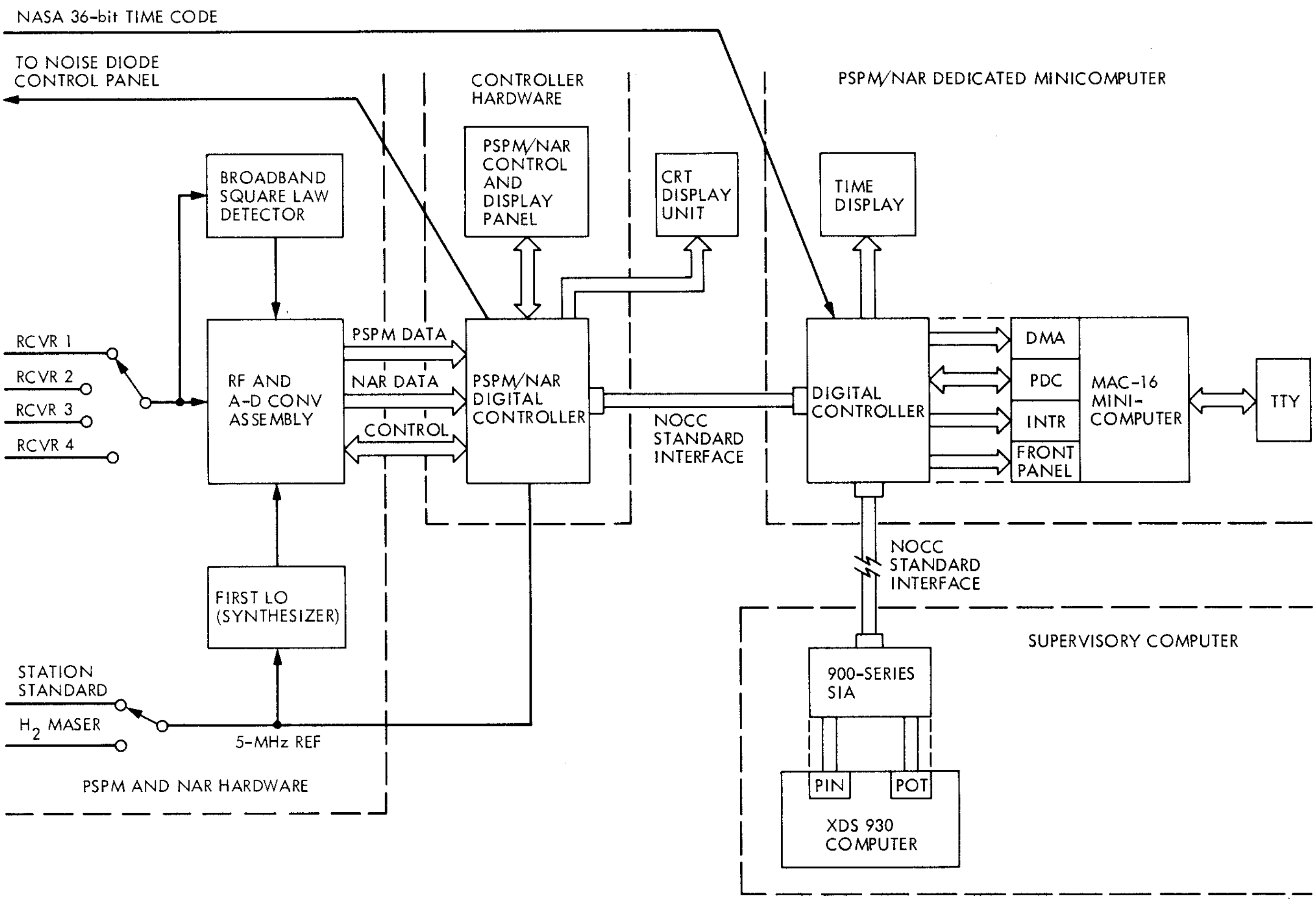

Fig. 2. PSPM and NAR hardware configuration block diagram

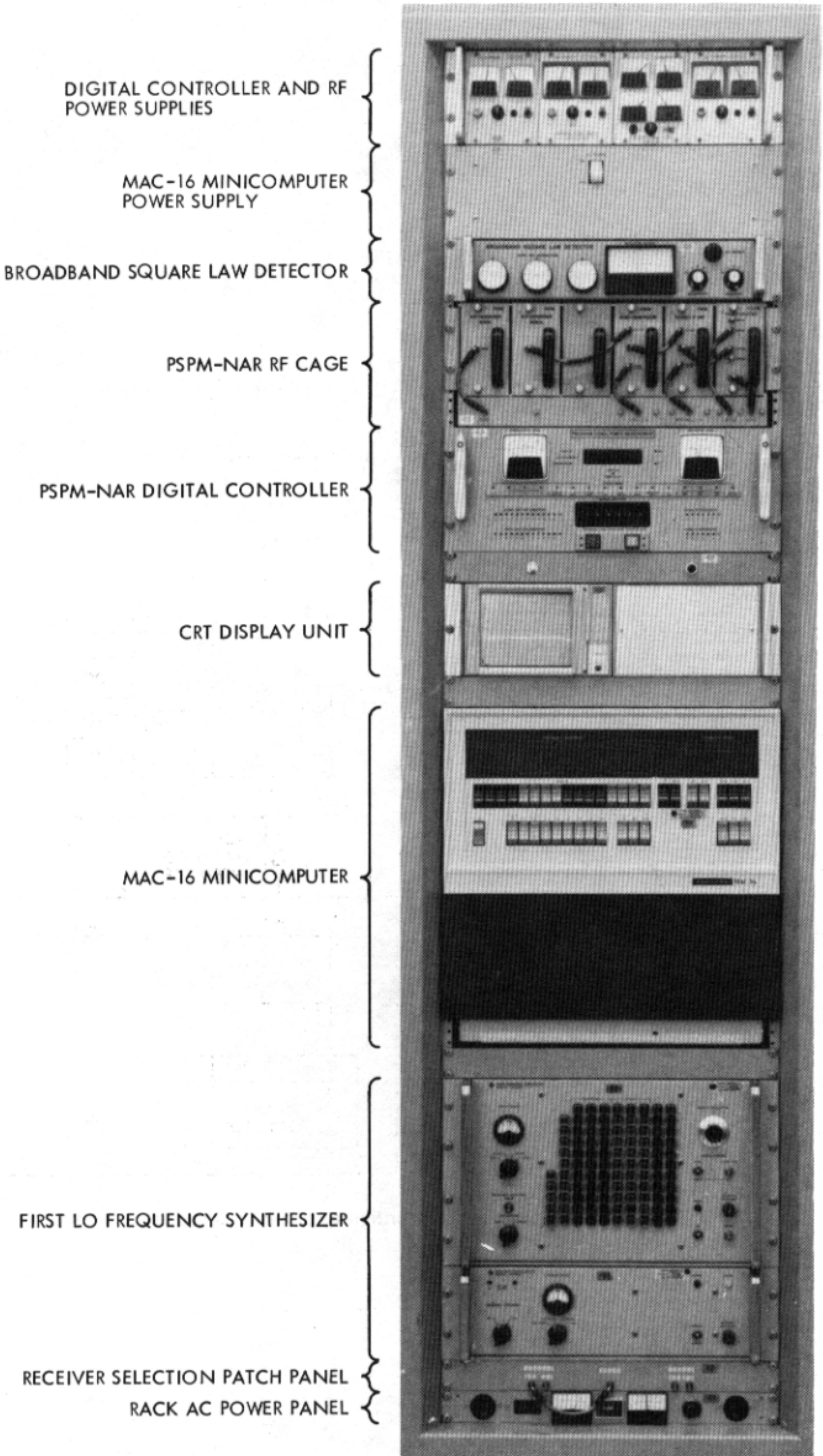

Fig. 3. PSPM and NAR equipment rack

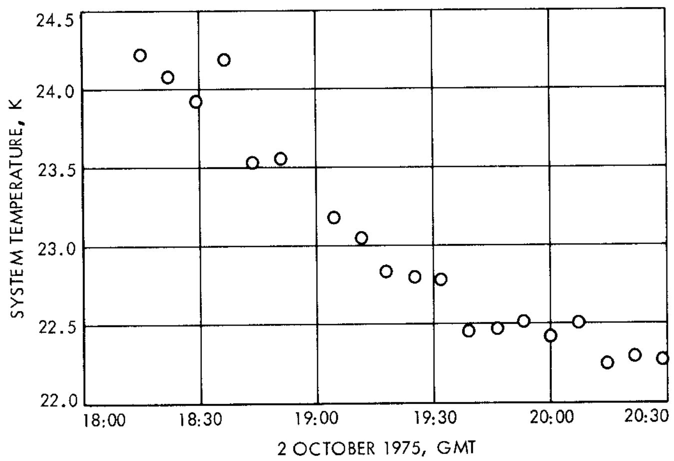

Fig. 4. System temperature measurement

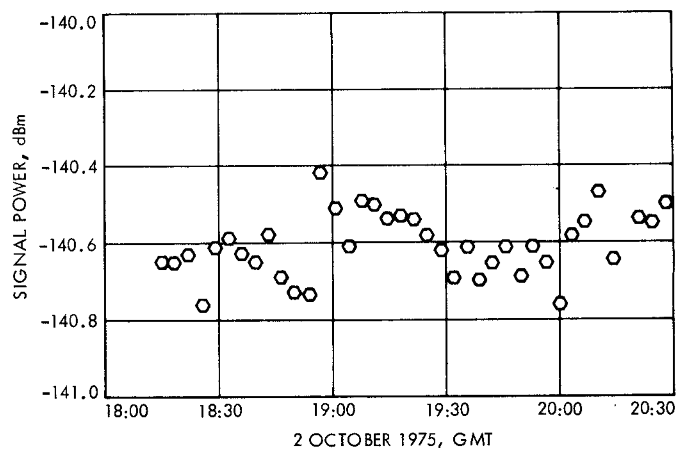

Fig. 5. Received signal power measurement